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Table of Contents – April 2010

Editor's Note: This article provides interesting and evocative research. The principle is well researched and the practice was very broad. The findings in Research Question 2 have considerable significance for design of learning. and the research findings from Research Question 4 provide considerable direction for optimal design of effective of learning materials.

The Impact of Multiple Representations of Content using Multimedia on Learning Outcomes

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Abstract

Innovative educational technologies provide valuable opportunities for educators to design an enhanced, interactive, more inclusive and engaging curriculum. Key pedagogical motivations for utilising educational technologies include the desire to improve learning performance and engagement. Educational technology and access to multimedia have provided opportunities to present multiple representations of key content areas using multimedia (text-based, video, aural, interactive elements) to cater more effectively to different learning styles and model preferences. This paper presents the findings of an experiment to measure the impact of multiple representations of content on learning outcomes including learning performance and engagement. While, in this study, multiple representations of content did not lead to actual improvements in learning performance, students reported favourably on multimodal learning elements and perceived that they had assisted comprehension and retention of the material. Implications for educators, limitations of the experimental methodology and directions for future research are presented.

Keywords: multiple representations; multimodal; multimedia; educational technology; interactive; learning styles; modal preferences; learning outcomes; learning performance; engagement

Introduction

In the field of distance education, traditional print-based materials are being converted to more interactive, multimodal, technology-mediated e-learning formats. Multimedia enhancements include, for example, video and audio elements, recorded lecture presentations, interactive audio-enhanced diagrams and simulations, interactive quizzes and crosswords, and graphics. Multimedia can be used to represent the content knowledge in ways that mesh with different learning styles and appeal to different modal preferences (Birch & Sankey, 2008; Moreno & Mayer, 2007). The concept of learning styles proposes that "different people learn information in different ways" (Pashler, McDaniel, Rohrer & Bjork, 2008, p. 106). Modal preferences refers to the existence of study preferences; that is, "the fact that people will, if asked, volunteer preferences about their preferred mode of taking in new information and studying" (Pashler et al., 2008, p. 106).

Multimodal learning

In recent years, multimedia in conjunction with hypermedia have been successfully applied to many e-learning environments in order to cater to a wider variety of student learning styles and modal preferences (Birch & Gardiner, 2005; Sankey & St Hill, 2009; Sprague & Dahl 2010). Fleming (2001) proposed that learners have a preferred learning style, namely, visual, aural, read/write or kinaesthetic, with many learners (about 40 percent) presenting as multimodal. As such, multimedia can be used to develop a more inclusive and engaging curriculum, appealing to visual, aural and kinaesthetic learners, thereby counteracting some differences in student

performance (Birch & Burnett, 2009; St Hill, 2000). To further support this concept, neuroscience research has revealed that "significant increases in learning can be accomplished through the informed use of visual and verbal multimodal learning" (Fadel, 2008, p. 12). Students have been found to feel more comfortable and perform better when learning in environments that cater for their predominant learning style (Cronin, 2009, Omrod, 2008). This is known as the "meshing hypothesis" (Pashler et al. 2008, p. 109). Presenting material in a variety of modes may also encourage students to develop a more versatile approach to their learning (Hazari, 2004). Within the field of cognitive science, recent findings suggest that,

> Multiple intelligences and mental abilities do not exist as yes-no entities but within a continua which the mind blends into the manner in which it responds to and learns from the external environment and instructional stimuli. Conceptually, this suggests a framework for a multimodal instructional design that relies on a variety of pedagogical techniques, deliveries, and media (Picciano, 2009, p. 11).

Multimodal e-learning environments allow instructional elements to be presented in more than one sensory mode (Mayer, 2003). Therefore, material presented in a variety of presentation modes may lead learners to perceive that it is easier to learn and improve attention rates, thus leading to improved learning performance, in particular for lower-achieving students (Chen & Fu, 2003; Moreno & Mayer, 2007; Zywno 2003). Mayer (2003) contends that students learn more deeply from a combination of words and pictures than from words alone; known as the "multimedia effect". Shah and Freedman (2003) discuss a number of benefits of using visualisations in learning environments, including: (1) promoting learning by providing an external representation of the information; (2) deeper processing of information; and (3) maintaining learner attention by making the information more attractive and motivating, hence making complex information easier to comprehend. Fadel (2008) states that, "students engaged in learning that incorporates multimodal designs, on average, outperform students who learn using traditional approaches with single modes" (p. 13).

A major benefit to multimodal design, as identified by Picciano (2009), is that it "allows students to experience learning in ways in which they are most comfortable, while challenging them to experience and learn in other ways as well" (p. 13). The non-linear design of the multimodal learning environment has been found to increase learners' control over the way that they progress through their materials (Karagiorgi & Symeou, 2005). Thus, students may become more self-directed, interacting with the various elements housed in these environments. Therefore, depending upon their predominant learning style, students may self-select the learning object or representation that best suits their modal preference (Doolittle, McNeill, Terry, & Scheer, 2005).

Different approaches to suit different learning styles and modal preferences

Integral to the design of the multimodal learning environments is the premise that students learn in different ways and that each student has a preferred learning modality (Sarasin, 1999). In other words, "different modes of instruction might be optimal for different people because different modes of presentation exploit the specific perceptual and cognitive strengths of different individuals" (Pashler, McDaniel, Rohrer, & Bjork, 2008, p. 109). This being the case, when learning environments are designed to cater to multiple sensory channels, information processing can become more effective (Kearnsley, 2000).

Fundamental to the design of learning environments are the principles of multimodal design in which "information (is) presented in multiple modes such as visual and auditory" (Chen & Fu, 2003, p.350). Although visual images are proven to be an integral part of human cognition, they have tended to be marginalised and undervalued in contemporary higher education (McLoughlin & Krakowski, 2001). If material such as verbal texts (audio), diagrams, drawings, photographs, and videos are all regarded as texts to be read, they can be applied to the development of new

inclusive curricula (Roth, 2002). It is necessary to develop strategies for the multiple representation of a whole range of instructional concepts to cater to the diversity of learners we have today.

The use of multiple representations, particularly in computer-based learning environments is recognised as a very powerful way to facilitate understanding (Moreno, 2002). For example, when the written word fails to fully communicate a concept, a visual representation can often remedy the communication problem (Ainsworth & Van Labeke, 2002). Some simple examples of multiple representations include, using point-form text or images with audio enhancement in the form of mini-lectures for various topics (Figure 1), interactive diagrams with accompanying transcripts and voiceovers (Figure 2), video presentations, interactive graphs and forms, audio explanations of concepts, and still images.

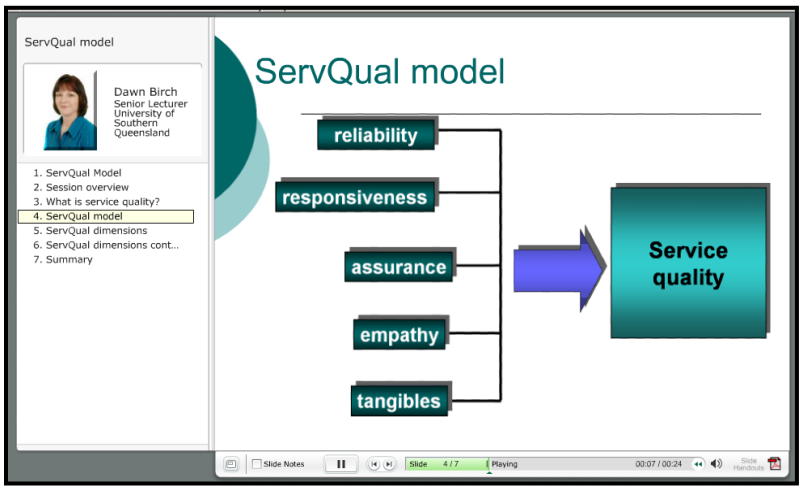

Figure 1: Audio-enhanced PowerPoint presentation

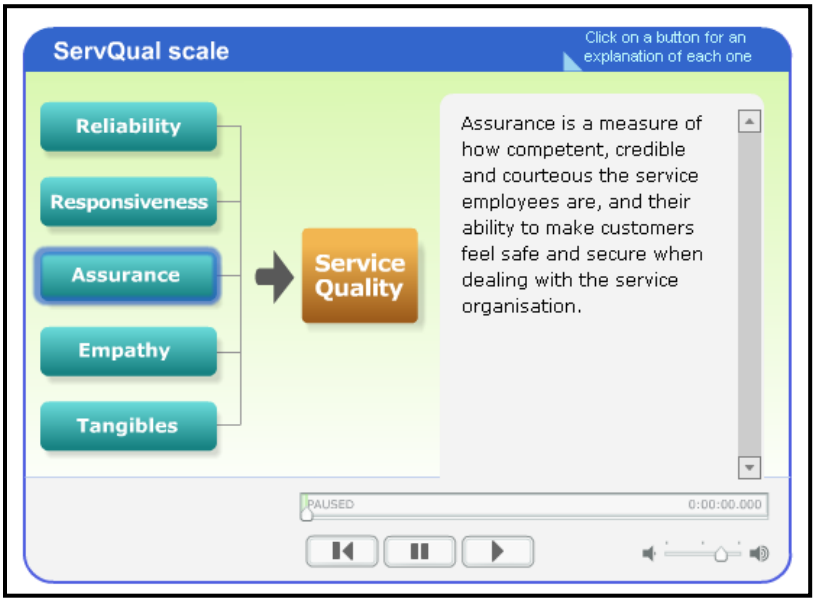

Figure 2: Interactive narrated diagram with a text-based transcript

In the examples provided above (Figures 1 and 2), the multimedia elements (visual, aural, and interactive elements) present additional representations of the information traditionally provided in text-based explanations. This approach caters for a range of different learning styles and modal preferences. It gives students choice in how they can access course content, and thus may be considered a more ethical and inclusive response to the needs non-traditional learners.

Facilitating Metacognition

Educators may try to design for all the different learning styles, however limitations exist arise because many students "don't even realise they are favouring one way or the other, because nothing external tells them they're any different from anyone else" (DePorter, 1992, p.114). Therefore, although it has been seen that there is a real need to design learning environments to cater for a range of different learning styles and modal preferences to aid student cognition, consideration of students' metacognition is equally necessary. Therefore, a further aspect needs to be considered, namely, helping individual students become aware of their own preferred approach to learning.

It has been suggested that when students are aware of their individual strengths and weaknesses as learners they become more motivated to learn (Coffield, Moseley, Hall, & Ecclestone, 2004). The potential of this awareness is that students can then question their long-held beliefs or behaviours and be taught to monitor their selection and use of a range of strategies to aid their learning (Sadler-Smith, 2001). This strategy has also been shown to increase the confidence and the grades of students by helping them to make the most of the learning opportunities that match their preferred style (Coffield, et al., 2004). To determine their predominant learning style, students can be encouraged to complete some form of learning styles inventory. McLoughlin (1999) emphasises that "teaching students how to learn and how to monitor and manage their own learning styles is crucial to academic success" (p.231).

The need for evidence of the learning styles hypothesis

Despite the ongoing call for evidence-based practice, difficulties in assessing the impact of educational technologies on learning outcomes have been reported due to the need to provide all students with the same opportunities (Cronin 2009; Forte & Bruckman 2007; Mayer, 2009). This study sought to address the dearth of experimental studies to test the "meshing hypothesis"; that is, the claim that instructional resources should mesh with the student's learning style (Pashler et al. 2008, p. 108). The problem investigated in this research was to determine the impact of multiple representations of content on learning outcomes across learning styles and modal preferences. Four research questions were developed to investigate the research problem.

1. Do multiple representations of content lead to improved learning outcomes and does this vary across learning styles and modal preferences?
2. What types of representations of content (visual/aural/text/kinesthetic elements) lead to improved learning outcomes and does this vary across learning styles and modal preferences?
3. Do multiple representations of content lead to cognitive overload, thus reducing learning outcomes and does this vary across learning styles and modal preferences?
4. What is the optimal combination of representations of content for improving learning outcomes and does this vary across learning styles and modal preferences?

Methodology

The main purpose of the research was to establish a cause-and-effect relationship between the ways in which content is presented to students and learning outcomes. Differences across

predominant learning styles (visual, aural, read/write, kinaesthetic, multimodal) and modal preferences were also investigated. An experimental design was selected to allow for the manipulation of the ways content was presented and the measurement of students' learning performance. A post-experiment survey was conducted to identify modal preferences by investigating which learning elements were considered to be most helpful in assisting learning.

Undergraduate and post-graduate students studying at the University of Southern Queensland, Australia were emailed to seek their participation in the experiment. An incentive of an AUD$30 university bookshop voucher was used to encourage participation. To determine students' predominant learning style, students were requested to complete the VARK learning styles inventory online (http://www.vark-learn.com/english/page.asp?p=questionnaire) and to email their VARK scores and result (predominant learning style) to the researchers.

The experiment itself involved the development of two learning concepts, both drawn from services marketing theory. The first concept concerned customer satisfaction and addressed the 'expectancy disconfirmation model'. The second concept concerned the measurement of service quality and focussed on the ServQual model. Neither concept is particularly difficult to understand. Students who had previously studied services marketing were excluded from the experiment to control for prior learning. The learning material was presented in six different ways (conditions) with an additional representation of the content being added for each subsequent condition, with Condition 6 representing the highest number of representations of content used in this experiment. (see Table 1).

Table 1

Learning Conditions Used in the Experiment

Representations of Content					
Condition 1	**Condition 2**	**Condition 3**	**Condition 4**	**Condition 5**	**Condition 6**
• Text	• Text	• Text	• Text	• Text	• Text
• Study guide	• Study guide	• Study guide	• Study guide	• Study guide	• Study guide
	• Printed PowerPoint	• Printed PowerPoint	• Printed PowerPoint	• Printed PowerPoint	• Printed PowerPoint
		• Recorded PowerPoint with audio	• Recorded PowerPoint with audio	• Recorded PowerPoint with audio	• Recorded PowerPoint with audio
			• Interactive diagram with script only	• Interactive diagram with audio only	• Interactive diagram with script and audio

Sixty students were recruited, allowing for ten students in each of experimental groups (each student was exposed to two learning concepts across two different learning conditions), with the aim being to include two students from each of the five learning styles (visual, aural, read/write, kinaesthetic, and multimodal) in each group. However, only four of the students who agreed to participate in the experiment had a predominant aural learning style. The most common learning style from the students agreeing to participate in the experiment were multimodal learners, so

where a shortage of students with one of the predominant learning styles existed, a multimodal learner was included to make up the number for each group.

The experiment was conducted in two computer laboratories at the University. As students needed to access the multimodal presentations via computer, the learning conditions and the post-experiment survey were housed on a separate website. When the students entered the website, they were instructed to select their assigned group and then follow the instructions in working through the learning conditions. To measure learning and assess prior knowledge or understanding, all students were asked to complete an identical pre-test comprising multiple choice questions for each concept and then to complete a post-test (identical in content to the pre-test) once they had been exposed to each learning concept.

To control for confounding factors, a standardised set of instructions, format and setting were used for every group. Students were told that the purpose of the experiment was to measure the impact of various learning resources on learning outcomes and to determine if these varied across learning styles and modal preferences. Students were instructed to carefully work through each learning concept to ensure that they did all of the required reading, listening and interacting with all of learning elements within each condition. Before the commencement of the experiment, students were provided with information about the experiment and asked to sign an informed consent form. Students were assured of anonymity and confidentiality.

Demographic data for each participant was gathered from university records including gender, age, program and grade point average. A post-experimental survey was developed to gather students' perceptions of the learning elements they were exposed to during the experiment. Students were asked which of the two learning concepts they found to be: (a) easiest; and (b) most enjoyable to learn. Six open-ended questions provided all students with an opportunity to express what they felt had been the most helpful resource/s they had been exposed to during their interactions with the two allocated learning conditions and why. These qualitative measures were administered to provide students with the opportunity to give a more in-depth account of their encounter with the multimodal learning environment (Barker, Pistrang, & Elliott, 2002).

Findings and Discussion

Of the sixty students participating in the experiment, approximately two thirds (68.4%) were females and one third (31.6%) were males. Students across a broad age range participated in the experiment with the youngest students being 17 years and the eldest student being 60 years. The majority of students were under 30 years of age (70.0%).

The proportion of students with each learning style is presented in Table 2. The majority of students in the study had a predominant multimodal learning style (35.0%), with equal numbers of kinaesthetic (21.7%) and read/write (21.7%) learners. Visual (16.7%) and aural (6.7%) learners were under represented in the sample. There were differences in learning styles across gender. The males in the sample predominantly had a multimodal (52.6%) learning style with no visual learners, while females were more evenly distributed across multimodal (26.8%), visual (24.4%), kinaesthetic (22.0%) read/write (19.5%) learning styles. There were very few aural learners in the sample with only 7.3 percent of females having an aural learning style and only 5.3 percent of males.

The majority of the students in the sample (60%) had a grade point average of 5.0 or above (out of 7.0) with only 8.0 percent of students with a grade point average of less than 4.0, indicating that very few lower-achieving students elected to undertake the experiment. There were no significant differences across the six experimental groups with respect to gender, age or grade point average.

The research problem investigated in this study sought to determine the impact of multiple representations of content on learning outcomes across learning styles and modal preferences.

Table 2
Learning styles of participants

Predominant learning style	Female	Male	Total
Visual	10 (24.4%)	0 (0%)	10 (16.7%)
Aural	3 (7.3%)	1 (5.3%)	4 (6.7%)
Read/write	8 (19.5%)	4 (21.1%)	12 (20.0%)
Kinaesthetic	9 (22.0%)	4 (21.1%)	13 (21.7%)
Multimodal	11 (26.8%)	10 (52.6%)	21 (35.0%)
TOTAL	41 (68.4%)	19 (31.6%)	60 (100.0%)

In addition to the experimental data, a thematic analysis of the qualitative data was conducted on students' responses to the six open-ended questions. An initial scan of the 333 comments made to the open-ended questions was performed using the qualitative analysis tool, Leximancer, to provide an initial feel for the potential themes contained within these data. The Leximancer scan revealed a considerable cluster of concepts around the key words of; information; reading; learning; audio; concept; diagram; learn; helpful and easier. From this investigation, the analyses of these qualitative data continued using NVivo software to explore four main themes:

1. The usefulness of having a combination of resources (139 comments)
2. The usefulness of audio (50 comments)
3. The place of reading within online environments (59 comments)
4. The right amount of choice (14 comments)

These four themes will be explored in relation to the four research questions, in turn.

Research Question 1: The first research question concerned whether multiple representations of content lead to improved learning outcomes and whether this varies across learning styles and modal preferences. The majority of students (93.4%) improved from the pre-test to the post-test after being exposed to the learning materials for Learning Concept 1 with the average change in performance from pre-test to post test being 41.4 percent. Likewise, the majority of students (91.8%) improved from the pre-test to the post-test after being exposed to the learning materials for Learning Concept 2 with the average change in performance from pre-test to post test being 48.3 percent. Learning Concept 1 was perceived to be easier to learn than Learning Concept 2 by the majority of students (58%). However, the majority of students enjoyed Learning Concept 2 (57.39%) more than Learning Concept 1. While students were asked not to guess the answers and to select 'don't know' where they did not know the answer, many students did select both correct and incorrect answers in the pre-test indicating some use of logic and/or guessing. The learning concepts used in the experiment were not difficult, and thus it may have been possible to make a logical assumption or an intelligent guess from the questions asked.

The experimental data did not reveal any differences in learning performance across the six groups and the six different conditions for either of the two concepts. This lack of support for the learning style "meshing" hypothesis is consistent with the findings of other experiments

conducted by Massa and Mayer (2003) and Constantinidou and Baker (2002). However, it should be emphasized that the sample sizes (ten per cell) were too small to make any statistical inferences. Moreover, some methodological limitations were evident including the lack of participants with aural and visual learning styles, the possibility that the concepts were too simple or common sense resulting in inflated pre-test scores due to correct guessing and/or logic, the unnatural research setting, possible testing effects, and self-selection of students with higher average grade point averages (the average GPA of the participants was 5.06/7.00). Given the literature indicates that multimodal learning may be of greater benefit to lower-achieving students, while higher achieving students perform well regardless of how the content is presented, this could provide some explanation for the lack of impact of multiple representations of content on learning performance within this experiment (Zwyno, 2003).

Research Question 2: The second research question sought to determine which types of representations of content (visual/aural/text/kinaesthetic elements) lead to improved learning outcomes, and whether this varies across learning styles and modal preferences. While there were no differences across learning performance, most students indicated that all of the learning resources were helpful with the more enhanced multimodal learning resources considered to be the most helpful. Using the Friedman test, a ranking of the treatments was possible as indicated in Table 3. This finding indicates that the enhanced PowerPoint with audio and interactive diagrams with audio and transcript were significantly different to the other learning resources, with these two resources being considered to be the most helpful to the student learning experience. These two elements (included in condition 6) comprise greater representations of content and include visual, aural, text-based and kinaesthetic elements, aimed at appealing to a variety of learning styles and modal preferences.

Table 3
Perceived helpfulness of learning resources (7 point scale)

Learning resource	Mean	Ranking
PowerPoint with audio	5.62	1
Interactive diagram with script and audio	5.42	1
PowerPoint handout	4.22	2
Study guide	4.16	2
Interactive diagram with script only	4.20	2
Textbook reading	3.98	2
Interactive diagram with audio only	3.66	2

While the sample is too small to draw any statistical inferences, the data indicates (Table 4) that kinaesthetic learners, in particular, found the recorded PowerPoint presentations to be very helpful, while aural learners found the interactive diagram with transcript and audio to be very helpful. It is also interesting to note that the visual and kinaesthetic learners rated the textbook reading as being the least helpful, while the aural and read/write learners rated the interactive

diagram with audio only as being the least helpful. This could indicate that visual and kinaesthetic learners may be at some disadvantage when the learning resources are primarily text-based.

Table 4
Perceived helpfulness of learning resources across learning style
(7 point scale)

Learning resource	V	A	R	K	MM	Ave
PowerPoint with audio	5.7	5.7	5.1	6.5	5.1	5.62
Interactive diagram with script and audio	5.7	6.5	4.3	5.3	5.3	5.42
Study guide	4.1	3.3	5.2	4.6	3.9	4.22
Interactive diagram with script only	3.5	4.7	4.0	4.2	4.4	4.16
PowerPoint handout	3.3	3.0	3.8	5.1	4.7	3.98
Textbook reading	2.3	5.5	4.7	2.6	3.2	3.66
Interactive diagram with audio only	3.5	2.5	2.4	4.4	3.2	3.20

Students were also asked open-ended questions concerning the various learning resources. Responses indicated that students have modal preferences for learning, and in many cases, in keeping with their predominant learning style. Many students commented on how the various learning resources assisted them in understanding and retaining the content, while others commented on which learning resources were easiest, more interactive or more enjoyable to use. A selection of student comments, across the various learning styles, is provided in Table 5.

The thematic analysis of the qualitative data revealed two major themes related to Research Question 2. The first theme related to the usefulness of audio (50 comments), and the second theme, related to the place of reading within online environments (59 comments). The use of audio in online learning environments has long been purported to provide advantages for student learning (Clark & Mayer, 2003; Fahy, 2005; Hazari, 2004). This finding was certainly confirmed and reinforced in this study. However, it is when audio is used in conjunction with other resources, such as images or text, that the advantage is most prominent. In the case of the study materials used for these environments, audio was provided in two main resources; the audio-enhanced PowerPoint presentations and in the interactive diagrams (with or without a transcript). The audio component was mentioned some fifty (50) times in the qualitative data, and on nineteen (19) of these occasions, audio was perceived to be a necessary component. This combination of resources was not only seen to provide information, but also led to a greater perceived understanding of the materials being presented and made learning more enjoyable. Previous studies have established that using a combination of verbal and non-verbal approaches, that stimulate both visuals and audio modalities, can increase working memory (known as "Dual Coding Theory") and have a significant impact on how students retain information, and consequently make learning more enjoyable (Calandra, Barron & Thompson-Sellers 2008; Clark & Mayer, 2003; Pavio, 1991). The following comments exemplify these attributes:

Table 5

A sample of comments regarding learning resources across learning styles

Learning style	Comments regarding different learning resources
Visual learners	▪ I enjoyed being able to interact with the buttons on the diagram ▪ The resources were more interesting and interactive ▪ I prefer having a visual aid while listening to the speaker ▪ There was less information to read – less information overload ▪ The combination of reading and listening was good ▪ The audio learning was the easiest, along with a visual aid being in the diagram ▪ It had a flowchart diagram which made it easy to organize the concept in my head ▪ I was able to listen to the slide show and see the words with pictures as they were spoken ▪ I did not enjoy Learning Concept 2 as there was no audio or diagrams. I find learning easier with additional aids. ▪ I could learn the same knowledge in a different way, which let me check my understanding fully ▪ The most helpful is the diagram with script and audio as there are two different modes of learning available.
Aural learners	▪ I like to see something and also hear it ▪ The visual provided a much better understanding ▪ Reading the visual diagrams certainly aided in memory retention ▪ The interactive diagram assisted with retaining information
Read/write learners	▪ I find the reading the most useful and I tend to get distracted with listening and I tend to understand more with reading ▪ Listening and reading was better for me ▪ I liked information in the written form ▪ I found the recorded lecture helpful with definitions and a summary of important points ▪ Lists appeal to me ▪ I found Learning Concept 1 easier because it was just reading, but in Learning Concept 2 you got to read it a few times and that helped me understand ▪ Repetition of the learning objectives helped ▪ Clicking on topics had definitions popping out of the screen ▪ I enjoyed reading the materials, but having a real person's voice added a personal element ▪ I liked the interactive part because it was fun to play around while learning ▪ A mix of stimulus material which tends to be better for maintaining concentration/focus on the topic – short/sharp tasks

Kinaesthetic learners	▪ I enjoy listening and seeing ▪ The combination of audio and visual kept me a bit more interested ▪ It was much more interesting to listen and interact ▪ It is more interesting to hear an actual person speaking about it ▪ It was more attractive and normally visual mechanics seem better tools for learning for me ▪ There were a couple of different ways I could learn the material. I didn't just have to read the material ▪ The interactive study guide with audio helps to cement my knowledge – also the interactive diagram ▪ The diagram really helped. The colors helped me when I was picturing what I had learnt ▪ Hearing the information spoken and maybe put into different words than the text book helped me to get a fuller understanding ▪ I could see what was being presented and therefore could recall the information much easier ▪ The audio reinforces what is being read ▪ The audio made concepts more confusing – like it clouded over what was supposed to be a simple concept
Multimodal learners	▪ I could first read a clear definition, and then I could see a diagram, and then I could listen ▪ Pictures that I click on made it easier to understand the flow and having the audio to read while I was looking at the diagram ▪ There was a variety of different approaches to learning the material and I could utilize all of them if I wanted ▪ The information was presented through the audio visual element which reinforced things ▪ A tangible and visual effect that enforced my learning capacity ▪ Someone explaining the concepts to me rather than just visual textual resources ▪ The interactive diagram was fun to do as I got to click on things while the PowerPoint slides had little pictures on them ▪ It is hard to focus on reading the text for a long time. Interactive learning is easy and more importantly it is enjoyable.

I enjoyed reading materials for both concepts, but hearing a real person's voice as part of Concept Two added a personal element that made learning more enjoyable. (Read/write learner)

Hearing the information spoken and maybe put into different words than the text book helps me to get a fuller understanding. (Kinaesthetic learner)

I think hearing the information helps my recall. The diagrams I can "picture" in my mind when recalling information. (Kinaesthetic learner)

The second theme arising from the thematic analyses concerned the place of reading in online learning environments. The fifty nine (59) comments about the reading materials (electronic and hardcopy) provided fell into three main categories; the lack of interest in using reading materials or the boring nature of the reading (40); the perceived sufficiency of the written materials provided (17); and two requests for less reading. In relation to the lack of interest in using reading materials or the boring nature of the reading, some students commented:

> *Even though I always do my textbook readings I find them long and boring and I get distracted easily when reading them. (Read/Write learner)*
>
> *I lose my concentration when I'm simply reading, especially if it's new information. It's more interesting to hear someone speaking about something, as it's more personal. (Kinaesthetic learner)*
>
> *Simply reading a text book doesn't engage me and I tend to become disinterested and start skimming through the text, identifying only what I believe I may be assessed on and not take in a lot of what is in the text. (Kinaesthetic learner)*
>
> *I found the text book reading the least helpful because I found it to be less fun and sort of boring. It was overwhelming with all of the text and I found that I couldn't understand it as well as I could with the interactive diagram. (Multimodal learner)*

These comments should not be judged in isolation, rather they should be considered in conjunction with the finding concerning the usefulness of providing a combination of resources. To illustrate this connection:

> *It was much more interesting to listen and interact, as I find that when I'm just reading I have to read over and over again for the concept to sink in. It is helpful to have things explained several times and in several different ways. It was helpful to listen at the same time as reading, as extra information was added on in the sound. (Kinaesthetic learner)*
>
> *Having an aural aid [for Concept 2] made the concept more enjoyable, compared to Concept 1 where just reading it on my own was less enjoyable. (Multimodal learner)*

Research Question 3: The third research question sought to investigate whether multiple representations of content lead to cognitive overload, thus reducing learning outcomes and whether this varies across learning styles and modal preferences. The experimental data did not indicate that multiple representations of content led to cognitive overload, thus reducing learning outcomes. No differences were found across the six conditions for either concept. However, the thematic analysis revealed comments concerning the perceived potential for cognitive overload and the perceived right amount of materials to be provided. Some students commented on being given too much choice (15 comments) with statements such as:

> *Having the audio made concepts more confusing - like it 'clouded' over what was supposed to be a simple concept. (Kinaesthetic learner)*
>
> *The first Concept for me was information overkill, it appeared that there was so much for me to absorb with the diagram as well as the reading. (Visual learner)*
>
> *More repetition of what was already learned, just another visual of what I had read. (Read/Write learner)*

Indeed, some students found it sufficient to simply read their materials. For example:

> *The readings gave me what I needed to know without fluffing around with extras that may well have confused me, the information got straight to the point.(Visual learner)*

I find the reading the most useful and I tend to get distracted with listening and I tend to understand more with reading. (Read/Write learner)

Having seen that there can be some concerns around having too much choice, albeit that these comments are very much in the minority, there is sufficient evidence to suggest that a scaffolded approach, utilising a combination of learning materials (a multimodal approach) to the provision of key information may be optimal. Pashler, et.al. (2008) state that "It is undoubtedly the case that a particular student will sometimes benefit from having a particular kind of course content presented in one way verses another" (p. 116).

Research Question 4: The fourth research question sought to determine whether there is an optimal combination of representations of content for improving learning outcomes and whether this varies across learning styles and modal preferences. The experimental data did not reveal any statistical differences across learning conditions or learning styles with respect to learning performance. However, the qualitative data indicated that there may not be any optimal combination, with learners both within and across different learning styles expressing different preferences with respect to the learning resources. The thematic analysis revealed that a combination of resources was considered to be particularly useful (139 comments). Providing more than one representation of a particular concept was found to be the most valuable attribute of the materials. The following comments typify the sentiments being expressed:

I was able to access various types of learning materials which helped in the understanding of the material. After listening to the resources, I found it easier to take in what the material was trying to teach me, it reinforced it in my head. (Kinaesthetic learner)

There was a variety of different approaches to learning the material and I could utilise all of them if I wanted.

The combination of reading and listening was good. I do not find it easy to learn when I am just reading. By having the two resources I was seeing and hearing the information twice which helped. (Multimodal learner)

It combines two powerful teaching styles; visual and audio. When you can integrate two or more teaching styles together, there is greater potential for learning. (Multimodal learner)

Hence, a choice of resources and the reinforcement that choice allowed were fundamental to the students' appreciation of the learning environments. The main finding here may be that students like to have options and will gain benefits from those learning styles most suited to their learning style or modal preference.

Implications, limitations and directions for future research

While the experimental data for this study did not indicate that students perform better under multiple representations of content, the qualitative data clearly indicates that students have modal preferences for learning and perceive learning resources with higher representations of content to assist their comprehension, understanding and retention of content, and to be more interesting and enjoyable to use. In particular, students expressed a strong preference for a combination of learning resources and options. Given these findings, the importance of improving student progression and retention, and engendering a joy of learning leading to life-long learning, educators should be encouraged to continue to explore the use of educational technology and multimedia for developing multiple representations of content. Recorded PowerPoint presentations and interactive diagrams with transcripts and audio, in particular, were valued by students in this study.

A number of limitations should be considered before drawing conclusions from this exploratory experimental study. First, it is difficult to make any inferences from the quantitative data regarding the impact of providing multiple representations of content on learning performance due to small sample and limitations of the experimental methodology. In addition to the small sample size, there was a predominance of: (1) higher-achieving students; (2) multimodal learners who typically learn across a range of conditions; and (3) a lack of aural and visual learners in the sample. Given the literature indicates that multimodal learning may be of greater benefit to lower-achieving students, while higher achieving students perform well regardless of how the content is presented, this may be one factor that explains the lack of impact of multiple representations of content on learning performance within this experiment (Zwyno, 2003). Future research should involve a larger sample, higher representation of lower-achieving students, and a more even representation across learning styles. Future research could also involve more complex concepts to allow for a stronger measure of improvements in learning performance across pre and post tests.

A larger and more representative sample could be recruited to allow for an empirical investigation of the impact of using educational technologies for developing multimodal learning resources across various groups. For example, in addition to exploring differences across learning styles and modal preferences, differences across gender and age groups, lower versus higher achieving students, English Second Language (ESL) versus English First Language students (EFL), and on-campus versus distance learners could also be investigated. Moreover, the unnatural study conditions and difficulties in controlling for extraneous factors in an experimental design should be addressed (Sekaran, 1992). Ideally, future research would involve investigating learning performance under more natural study conditions to reduce possible testing effects. Under experimental conditions, students may be more actively involved in processing the learning content and pay greater attention to the content than they would in real life. The difficulties experienced with the experimental methodology in this study may provide some explanation for the dearth of empirical data on the impact of multimodal presentation of content on learning styles, despite calls from educators for evidence that technology-enhanced learning leads to improved learning outcomes.

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